Earthquake Impacts on Mountain Communities - Observations and Lessons from the Mw 7.8 Gorkha Earthquake of 25 April, 2015

S. Wilkinson[1], M. Whitworth[2], M. DeJong[3], B. Ghosh[4], P. Burton[5], S. Tallet-Williams[6], V. Novelli[7], G. Franco[8], T White[9], A Trieu[3], S Datla[10], T. Lloyd[10], K. Goda[11]

1 Newcastle University, 2 AECOM 3 University of Cambridge, 4 Mott MacDonald,5 University of East Anglia, 6 Imperial College London, 7 University College London, , 8 Guy Carpenter, 9 Arup, 10 AIR Worldwide, 11 University of Bristol

ABSTRACT: This paper summarizes some of the observations made by a reconnaissance team following the 25th April 2015, M_w 7.8, Gorkha, Nepal earthquake. The team was comprised of members of the UK-based Earthquake Engineering Field Investigation Team (EEFIT) who spent approximately one week collecting observations of damage resulting from the earthquake. The earthquake caused more than 9,000 fatalities and significant damage to unreinforced masonry, historic structures and temples. While the earthquake generated less-than-expected destruction around the urban metropolis of Kathmandu, it was particularly notable for its impacts on remote mountain communities due to landslides and rock falls. As these communities constitute a socioeconomically vulnerable group in a country still in its early development stages, the earthquake impacts were disproportionately high. Therefore it is important to understand how the resilience of these populations can be improved. This paper focuses on the event's impacts to these remote mountain settlements and emphasizes their high vulnerability and the need to address their risk specifically in mitigation plans in Nepal and elsewhere.

1 INTRODUCTION

At 11:56 NST (06:11 UTC) on the 25th April 2015, an earthquake with a moment magnitude of 7.8 struck Nepal. The epicentre was located at 28.147°N, 84.708°E near the town of Gorkha approximately 80km West of Kathmandu and had a focal depth of 19km (USGS 2015). The earthquake was reported to have caused widespread damage between the epicentre and area stretching to the East of Kathmandu. The earthquake also triggered an avalanche on Everest which caused the deaths of 19 climbers and Sherpas (April 2015 Nepal earthquake, 2015). As is usual with these events, the region was also hit by a number of aftershocks, the most noticeable occurring on the 12th of May 2015 at 12:51 NST with a moment magnitude of 7.3 and with an epicentre near the Chinese border between the capital of Kathmandu and Mt. Everest (USGS 2015). The EEFIT management committee decided to send a team to investigate the impacts of this earthquake. Mission members were selected from the EEFIT membership and are the authors of this paper[1]. The mission had the objective of collecting observations across a wide-ranging set of disciplines and topics, which will be presented in full within the EEFIT technical report currently in preparation. This paper focuses only on the impact of the earthquake on remote hilltop villages in Nepal and the challenges they and the Nepalese government faced during the immediate relief phase (which is still ongoing) and during the first stages of their long-term recovery. The paper also presents brief details of the performance of buildings in Nepal for context.

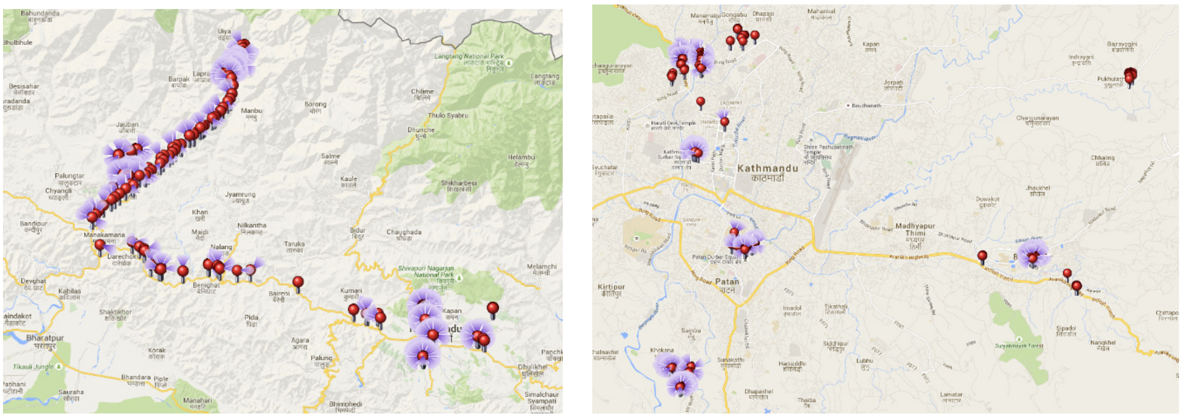
2 MISSION DETAILS

The team left the UK on the 12th June and returned on the 20th. The area was also visited by the Earthquake Engineering Research Institute (EERI) and by the Geotechnical Extreme Events Reconnaissance (GEER) group. Valuable exchanges of knowledge occurred between the teams.

The mission visited Kathmandu, Sangachok located approximately 40km East of Kathmandu and also travelled to Gorkha to observe damage near the epicentre. During the week of the mission, survey time was shared approximately equally between Kathmandu and surrounding districts and the Gorkha region and surrounding districts, with one trip in the region of the village of Sangachok. Figure 1 shows

[1]Co-author and EEFIT member K. Goda visited the area prior to the official EEFIT mission (see Goda et al. 2015). Co-author and EEFIT member T. Lloyd acted as team coordinator from London.

locations of the sites that were visited.



(a) (b)

Figure 1. Survey sites a) showing all sites and b) showing sites around Kathmandu. Note the densely packed line of markers in a). Each of these markers is the location and direction of a photograph that was taken during a helicopter flight to remote hilltop villages and each photo shows either a damaged village or a landslide. These photos will be made publicly available in the near future and are available immediately on request.

3 BUILDING TYPOLOGIES AND BUILDING DAMAGE

To help relate the damage resulting from this earthquake to other seismic events, it is necessary to understand the building typologies of the given region so that the damage can be described relative to other buildings of this type. The better constructed buildings located in Kathmandu were mainly reinforced concrete framed structures with masonry infill. The buildings were typically up to approximately 4 storeys high, but there were examples of structures up to 7 stories, with the tallest building encountered being 14 stories. These buildings were often very slender and it was surprising that many of these structures survived an earthquake of this magnitude. Pictures of surviving slender concrete buildings as well as a 14 storey structure are shown in Figure 2.

Figure 2. Reinforced concrete framed buildings with masonry infill.

There was also many two-storey masonry buildings as well as rubble masonry buildings. The masonry buildings consisted of low-fired clay bricks typical of regions such as this and were therefore weaker than well-fired bricks typically used in more developed regions. The rubble masonry was typically of poor construction and was common in poorer regions of Kathmandu as well as in outlying areas. Mortar in these buildings was often either very weak or sometimes without any form of binder. These buildings typically showed either complete or partial collapse and aftershocks were causing further collapse to already weakened structures or damage due to secondary collapses. Typical masonry structures are shown in Figure 3.

Figure 3. Example of partial collapse of a masonry structure near Kathmandu.

It was widely reported in the press that temples were badly affected and the mission confirmed this to be the case with a large number of religious and historical structures having suffered significant damage and sometimes, collapse.

An interview was conducted with the National Society for Earthquake Technology (NSET) in Nepal. One of the main objectives of this organisation is to improve the seismic safety and preparedness of Nepal and it has started a program of building and retrofitting schools. They have produced a number of standard designs for structures (both schools and other buildings) based on the size of the building and the number of storeys. These designs have drawings showing reinforced concrete details that would be typical for seismic regions with good engineering practice although it should be stressed that the authors of this paper have not yet done any detailed structural calculations to confirm their structural adequacy for the level of seismic risk faced by Nepal. The seismic hazard exposures for Nepal have been investigated and mapped by the National Seismological Centre in Kathmandu by Pandey et al. (2002) and by Chaulagain et al. (2015). In both cases the probabilistic seismic hazard analysis (PSHA) parameter mapped is peak ground acceleration (PGA).

There is awareness within the NSET that there may be a mismatch between these specifications and the ability of local labour to interpret them. They are currently producing simplified pamphlets and training to help remedy this situation. These standard designs may help explain some instances of good performance of buildings in Nepal. For example, Figure 4 depicts the column of a structure in the village of Sangachok that, although collapsed, shows good lap lengths for lapped bars (as did many buildings that were under construction) and reasonably closely spaced confinement reinforcement. It should be noted however that the concrete had very large aggregate in it and was not of good quality and the column dimensions were quite small (approx. 225mm square). The reason for the collapse of this structure is not clear, and could be either related to poor structural layout (causing a soft-storey collapse) or not all of the connections being well detailed. There was evidence of this latter point, but it is difficult to say for certain if either of these mechanisms were responsible.

Figure 4. Detail of column reinforcement.

4 REMOTE HILLTOP VILLAGES

It had been reported that landslides were a significant cause of deaths in the Gorkha region and also to the East of Kathmandu and that these were continuing to be a threat to remote villages. Landslide hazard and risk is endemic throughout the Himalaya and the fronting lower mountains and continuing risks of further landslides after an earthquake have been previously reported (Burton, and Peiris 2008 and Wilkinson et al. 2013). Furthermore landslides have also been observed to be a poorly appreciated risk in previous events (Wilkinson et al. 2012; Chian and Wilkinson 2015) and as there is likely to still be a significant seismic hazard in Nepal (Bilham 2015). The team aimed to visit the region affected by these landslides and travelled overland to the region. The team was able to liaise with the UN Office for the Coordination of Humanitarian Affairs (OCHA) who confirmed that landslides were a serious concern in the Gorkha region. The UN organised two EEFIT team members to be flown by helicopter to the villages of Yamagaum and Lapsibot in the region of Gumda. The aim was to observe how the earthquake had impacted remote mountain villages. From discussion with members of the UN and members of various NGOs and volunteers, the team had already established that these hilltop villages had been badly affected and that there may be evidence of the risk of further landslides.

The urgent demand for helicopters, necessitated very short visits to each of these villages (less than one hour in each). A third village on the itinerary (Machikhola) was not visited as it had been evacuated due to the risk of further landslides and it was deemed too dangerous to land the helicopter for the extra information that an uninhabited village may produce. The flight over the region enabled the team to see the scale of the situation in this region. Figure 1 shows a map with locations of the many photographs taken during the helicopter flight and each photo shows either a village with damaged buildings or a landslide (these photographs are available on request). The villages ranged from only a few dwellings to quite large villages and most had tarpaulins on the roofs of many of the structures. Those villages that the helicopter flew close to enabled the team to see that many of the buildings had suffered serious damage or had collapsed. It is expected that the two villages that the team landed at had similar levels of damage to those witnessed during the flight (the villages were chosen because of the landslide risk not because they had unusually high levels of building damage).). The diagrams in the Keefer (1984) suggest that coherent landslides in Nepal might extend up to approaching ~200 km distance from the Gorkha epicentre. One of the crucial larger earthquakes used by Keefer in his study was the great Bihar earthquake of 15 January 1934 in India-Nepal (8.3 M_w).

Upon landing at each village a meeting was held with the villagers and a number of questions were asked to ascertain what impact the earthquake had on life in the village from an engineering perspective. Other important impacts resulting from the earthquake such as health provision and food supplies were covered by a member of the UN team, also part of the visiting team to the mountain villages (Robertson 2015). The villagers reported that 24 neighbours had died as a result of landslides (most of the deaths had been farmers tending their fields and livestock) and nobody had died as a result of building collapses with only a few serious injuries sustained by this mechanism. The villagers reported that no one had yet supplied the village by overland routes (not even yaks or Sherpas) since the earthquake occurred as landslides had swept away the road and rebuilding efforts had not been successful with landslides continually severing the road. The only supplies provided thus far had been by helicopter.

4.1 *Yamagaum*

A rapid tour (approx. 30 mins) of the village and immediately surrounding slopes was made. This village is located on a steep sided hillslope in Gumda district. The village consists of 47 households, mainly rubble masonry construction with timber and corrugated steel sheet roofs. The construction quality of these dwellings is very poor. The mortar was very weak although it did have some form of binding material (most likely either cement or lime). Most of the buildings suffered either partial or complete collapse (examples are shown in Figure 5).

Figure 5. Examples of building and typical damage in Yamagaum.

The local school was also visited. This was of an even poorer construction. It is likely that no binder was used in the mortar and the school suffered complete collapse (see Figure 6). A temporary school had been constructed towards the bottom of the village and lessons were taking place during the visit.

Above the village tension cracks were observed in the terraced hillslope. The width of the cracks varied between approximately 10mm and 40mm and they ran parallel to the slope for approximately 50m. It should be noted that accurate observations of crack widths were hampered as locals had attempted to fill in the cracks. This operation was both observed and reported by locals who stated that the purpose was to prevent ingress of water. Other cracking was observed lower down the slope. Due to time constraints the exact extent and nature of the observed cracks were not established.

Figure 6. School building in Yamagaum.

4.2 ***Lapsibot***

This village lies on an adjacent hillslope in similar topography to Yamagaum. It was reported to consist of 85 households. These buildings are of a similar typology to Yamagaum, are of a similar construction quality and suffered similar damage patterns.

To the North-East of the village is a trail that follows a ridge that eventually descends into the village of Machikhola. During a walk along the ridge (the route of which can be seen in Figure 7) a small landslide was observed. Further along this trail a series of tension cracks were also observed running along the ridgeline. Example of these cracks can be seen in Figure 8. Due to time constraints the exact nature of this system of cracks and landslide could not be established. The observations terminated at a large landslide shown in Figure 9.

These general observations of landslide extent, building damage (grades 4 and 5 to highly vulnerable building stock A or B) and cracks in soil (extending to 40 mm width) observed through rapid observation with sparse coverage) all suggest intensity extending to IX or possibly X on EMS98.

Figure 7. Route of landslide survey.

Figure 8. Tension Crack.

Figure 9. Landslide in Lapsibot.

5 CONCLUSIONS

The damage observed to engineered structures in Kathmandu and surrounding areas is less than may have been expected. Many of the reinforced concrete structures were very slender with small structural members and yet they had survived an M_w 7.8 earthquake. The extent of damage or impact on the communities in Nepal should not be downplayed however, as damage to masonry and rubble masonry structures and temples was typically severe and there were many people still living in tents at the time of the survey. The reason for this less-than-expected damage is still unclear; however, some of the reinforcing detailing witnessed in reinforced concrete structures was good for a country at this stage of development and recent history as well as the ground shaking being concentrated in the long period range of 4-6 seconds and this may have also contributed to the survival rates. However, more work needs to be done to confirm the validity of these explanations as there were also large spectral accelerations recorded in the 0.2-0.6 second period range and many examples of poorly constructed buildings.

The hill villages are still in a difficult situation. Supplying these villages with essentials was proving difficult for the Nepalese government, the UN and NGOs. It was reported by the villages that were visited that overland supplies were not arriving as further landslides continued to sweep away the supply roads. A helicopter flight over the region showed that in every village a significant number of buildings (often most) had tarpaulins on their roofs and therefore had presumably suffered significant damage. This general observation was confirmed by the on-site inspection of two of the villages, where most masonry buildings had suffered partial or complete collapse (intensity IX). Finally the landslide risk remains and the arrival of the monsoon will increase this risk. Landslide hazard and risk is endemic throughout the Himalaya and the fronting lower mountains. The villages described in this paper showed evidence of stressed hillsides and with the onset of the monsoon season the risk of further landslides has increased. Based on this event and others, it seems that globally, there is an underestimation of earthquake-induced landslide risk and insufficient resources being devoted to mitigating this risk. The observations of the earthquake impacts in Nepal suggest that this should be a cause for concern for us all.

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